2 Perspectives for increased proton intensity for ISOLDE — HIP report excerpts

The High Intensity Proton working group (HIP) within the AB Department was formed in order to 'collect the needs of the various user communities, evaluate the benefits of the possible improvements and elaborate a preferred long-term scenario of the CERN accelerator complex. Short-term first priority steps had to be proposed, in line and consistent with the long-term scenario'. The conclusions are summarized in the report CERN-AB-2004-022 OP/RF [1], edited by M. Benedikt and R. Garoby and here only excerpts of the report, relevant for ISOLDE, will be repeated. The running of ISOLDE at the technical limit of 10 μA has radiation protection implications discussed in Chapter 6 and would require important changes at ISOLDE, e.g., changes to targets, target area and target handling system as described in Chapter 3. The implementation of the 900 ms cycling for the booster which is discussed in the text is not yet approved and can not be implemented before 2008. Except for minor rewriting to obtain language cohesion, no changes to the text have been undertaken.

2.1 Physics request

2.1.1 ISOLDE (short term)

ISOLDE operation does not generally interfere with high-energy physics, using PSB cycles that can not be exploited by the PS (case of PS cycle longer than one basic period). The nominal request is for 50% of the PSB cycles, which corresponds to an average of 1350 cycles/hour. At the maximum intensity of 3.2×10^{13} protons per pulse (ppp), the average beam current delivered to ISOLDE is then 1.92 μA.

2.1.2 ISOLDE (medium term)

The user community is expected to get larger and the proton flux has to grow and be brought as close as possible to the technical limit of 10 μA of the present experimental zone.

2.2 Performance of the accelerator complex

The only direct physics client of the PSB is the ISOLDE facility. The figure of merit for ISOLDE operation is the average number of available PSB cycles and the official request amounts to a minimum of 50% of the yearly cycles. This corresponds to an average of 1350 PSB cycles/hour of PSB operation for ISOLDE. Table 2.1 compares requested and available cycles for ISOLDE for the period 2006 to 2010.

Table 2.1: PSB cycles for ISOLDE operation in 2006, 2007 and 2010

Year	PSB physics operation [hours]	PSB cycles to ISOLDE		PSB cycles requested	
		[%]	[cycles/h]	[%]	[cycles/h]
2006	4500	48	1296	50	1350
2007	5400	45	1215	50	1350
2010	5400	47	1269	50	1350

As can be seen from Table 2.1, the ISOLDE physics request can be nearly fulfilled in the period 2006 to 2010. However, this is not fully satisfying, especially since the ongoing ISOLDE upgrade programmes will eventually lead to an increase of the request by a factor of five.

The overall conclusion is that the CERN accelerator complex, with the already ongoing improvements, can not provide all the requested beams in the period 2006 to 2010 in the assumed operational scenario. With the present capabilities of the accelerator complex, any wishes for higher beam availability or upgrading of CNGS and ISOLDE performance cannot be fulfilled. The production of the ultimate LHC beam is also not feasible with the currently used scheme.

2.3 Upgrades for radioactive ion beams

2.3.1 Present status and upgrade planning of the ISOLDE facility

The intensity limit for the present ISOLDE facility is determined by the radioprotection for target stations, and estimated at 10 μA [2], [3].

The production of the 1.4 GeV proton beam for ISOLDE involves only the Linac2 and the PSB machines. The present CERN commitment towards ISOLDE is based on a number of 'shifts' per year, corresponding to about 50% of the total number of PSB cycles and was usually fulfilled during the last years. With the PSB repetition time of 1.2 s and considering 90% beam availability this translates to 1350 pulses/hour. Multiplying this figure by the nominal PSB ISOLDE intensity of 3.2×10^{13} ppp gives an average current of 1.92 μA usually available for ISOLDE [4].

The demand coming from the ISOLDE community for the period 2006–2010 is for an increase of this figure up to the target limit of 10 μA, i.e., a factor of ~5. The present limitation in average current comes from both the maximum proton intensity that can be produced and the number of PSB pulses that are available for ISOLDE. These two points are therefore the key issues for an upgrade analysis.

2.3.2 Beam intensity limitations and improvement scenarios

The main limiting factor for the proton beam intensity that can be provided by Linac2 and PSB is the excessive incoherent space-charge tune shift that occurs at 50 MeV injection into the PSB. With an intensity of around 1×10^{13} protons per PSB ring, the vertical space-charge tune spread during RF capture exceeds 0.5 and the combination of several techniques is required to avoid large beam losses and to make high-intensity operation possible.

A horizontal multiturn scheme (10–13 turns) is used to inject the Linac2 beam into the PSB. To make full use of the available aperture, coupling of the transverse planes is applied during injection in order to transfer some of the horizontal oscillation into the vertical plane. Already during the injection process, the main magnetic field is ramped to accelerate the beam out of the space-charge regime as quickly as possible. A dual harmonic (h = 1 and h = 2 in anti-phase) RF system is employed to flatten the bunches during the capture process and the early acceleration phase to improve the bunching factor thereby reducing the incoherent space charge tune spread of the beam. Nevertheless a sophisticated resonance compensation scheme is needed to avoid the destructive effect of transverse betatron resonances up to third order. All these techniques have been studied and optimized over the last years. Very little margin is left for further improvements and no significant increase in beam intensity can be expected with the present operation conditions.

The only straightforward way to significantly improve the PSB beam intensity is to attack the problem directly at its roots, i.e., to reduce the space-charge tune spread at injection by increasing the injection energy. The space-charge tune shift is inversely proportional to $\beta\gamma^2$, and the experience of other laboratories having increased their linac energy confirms that the final accumulated intensity is roughly proportional to $\beta\gamma^2$ at injection. The Fermilab linac upgrade (1993, 200 to 400 MeV corresponding to a factor 1.7 in $\beta\gamma^2$) opened the way for an increase of the booster intensity from 3×10^{12} to 5.5×10^{12} protons per pulse [5].

Taking the requirement to make the LHC beam in a single batch as the final goal, the PSB intensity has to be increased by a factor two. This improvement should be obtained by increasing $\beta\gamma^2$ at injection by a factor two, i.e., by increasing the linac energy from the present 50 MeV up to 160 MeV. If the linac is upgraded, then it is almost mandatory to change the particle type from protons to H^- at the same time. This means to strongly modify the PSB injection area, but the advantages of a modern charge-exchange injection in terms of beam loss reduction, phase space painting options and emittance control clearly justify the investment. Simulations of 160 MeV H^- injection and accumulation in the PSB are in progress, and present results confirm the expected gain in intensity [6], [7].

The option of increasing the energy of Linac2 was considered but finally discarded owing to the limited energy achievable in the available space at the end of the linac, about 20 m. Using standard tanks at 202 MHz, only 80 MeV could be reached, at a cost of about 30 MCHF (P+M). The limited increase in PSB intensity would present only a minor interest for ISOLDE, and no significant advantages for the other users [8]. Higher gradients could be achieved by linac tanks at double frequency (405 MHz), allowing to reach about 100 MeV. However, the cost would be higher, on account of the completely new RF system to be designed and built, and the gain still marginal. Structures at higher frequency and gradient can not be used because of the low transfer energy.

The preferred solution is to build a new linac injector. Being the fourth linac to be built at CERN, the latter would naturally be called Linac4. This option has been recently studied in detail as an outcome of the SPL study. The energy of the original SPL room-temperature injector has been increased from 120 to 160 MeV, and its design can be directly used for the Linac4 [9]. The new linac would be housed in the PS South Hall, where the required 100 m space and the infrastructure (water, electricity, etc.) are largely available, and its beam would go to the PSB in a line parallel to the existing LEIR transfer line. Another factor contributing to lowering the construction cost is that most of the Linac4 makes use of 352 MHz RF equipment recuperated from the LEP machine. Moreover, an RFQ injector that can be used for Linac4 will be given to CERN by the 'Injecteur de Protons de Haute Intensité' (IPHI) Collaboration (CEA and IN2P3), at the end of their testing period in 2006. The fact that a modern linac would profit from technologies like low-energy chopping and collimation, intended to minimize beam losses and reduce the environmental impact of high intensity operation must also be taken into consideration. The target value of 6.4×10^{13} ppp in the PSB (factor two with respect to present peak intensity) could be reached with a linac delivering 30 mA H^- current during pulses of up to 500 μs length. The overall cost of a 160 MeV Linac4 in the PS South Hall, including the modification to PSB and the transfer line, has been estimated at 70 MCHF (P+M). Figure 2.1 shows a schematic layout of Linac4 in the South Hall.

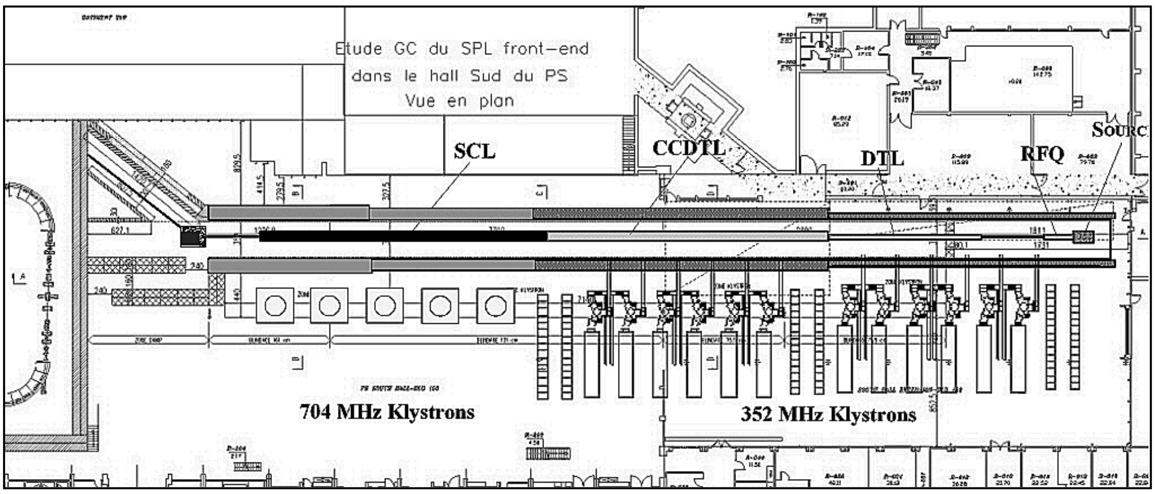

Fig. 2.1: Layout of Linac4 in the PS South Hall

2.3.3 *Increasing the number of PSB cycles available for ISOLDE*

Currently, on average, around 50% of the PSB cycles are made available for ISOLDE and the remaining 50% correspond to beams that are sent to the PS for the various other physics programmes on the PS and SPS. Since this ratio will not significantly change in the short and medium-term future, no changes for ISOLDE can be expected with the present operating conditions (see Section 2.4).

To increase the number of available PSB cycles for ISOLDE, in a transparent way for the other physics users, the total (yearly) number of cycles has to be increased. There are two approaches: prolong the PSB operation period or increase the PSB repetition frequency. With the latter option in mind several machine developments and studies were performed in 2001 and 2002 to investigate the feasibility of decreasing the PSB repetition time (and also the Linac2 repetition time) from the standard 1.2 s to 0.6 s [10]. The choice of 0.6 s was motivated by the fact that the PSB main power supply, after major upgrading in the framework of the 'PS for LHC project', just allows a 1.4 GeV magnetic cycle to be performed within 0.6 s.

The outcome of the investigations was that a repetition time of 0.6 s is feasible for Linac2 with only minor modifications (the machine was initially designed for 2 Hz operation) but too demanding for the PSB, pushing several essential machine systems towards or beyond their limits. Even though all physics beams could be produced on short 0.6 s cycles with nominal performance, several systems of the PSB would not support 24 h operation with 0.6 s cycling. In particular, the main power supply transformers (r.m.s. current limited), the first and second harmonics RF systems (r.m.s. power and cooling limited) and the main magnets cooling circuit would require major upgrade or replacement. In addition, several power converters in the transfer lines PSB–PS and PSB–ISOLDE would also need replacement so that the total cost for reducing the PSB repetition time to 0.6 s would be in the order of 10 MCHF and require significant manpower investment.

The situation is fundamentally different when analysing a reduction of the repetition time to 0.9 s. In this case, all PSB systems can operate within specifications, only a single transfer line power converter needs replacement and a few others some upgrade work. The overall cost can be roughly estimated to around 1–2 MCHF and accordingly less manpower is required so that a reduction of the PSB repetition time can be considered a valid short-term upgrade possibility.

The potential gain for ISOLDE is still important. With 0.9 s repetition time instead of 1.2 s, the number of PSB cycles in a given period increases by 33%. Assuming (to first order) that the 33% additional cycles are made available for ISOLDE (i.e., the number of cycles for other users remains unchanged) the gain factor is (50 + 33)/50 = 1.66 so that instead of 1350 cycles, as at present, around 2240 cycles would be available per hour for ISOLDE.

Obviously 0.6 s repetition time would be significantly more beneficial for ISOLDE (with assumptions as above the gain factor is (50 + 100)/50 = 3.0) but it requires ten times more investment than the 0.9 s option and does not benefit other CERN users in a way comparable to the Linac4 option for example.

Results of detailed calculations are given in Section 2.4.

2.3.4 *Estimate of short and medium-term ISOLDE performance*

The effect of the two potential upgrades on the performance of the ISOLDE facility is analysed below. The decrease of the PSB repetition time from 1.2 s to 0.9 s is considered a short-term option that could already be effective in 2006. The intensity increase by a factor two, expected from a new Linac4 is a medium-term option and could be achieved at the earliest by 2010. Combining the two options, the overall gain for ISOLDE would be $2 \times 1.66 = 3.32$, i.e., the average current to ISOLDE can be estimated to reach ~6.4 μA.

The different scenarios are summarized in Table 2.2. The number of cycles available for ISOLDE is compatible with all other physics requirements and especially the assumed LHC and SPS operation modes (see Chapter 3). The assumed intensities per PSB pulse are 3.2×10^{13} ppp with Linac2, and twice more, 6.4×10^{13} ppp with Linac4. The ‘gain factor’ is the ratio of the expected average current and the present average current of 1.92 μA (Section 2.3.1). In the case of Linac4 upgrade, it is assumed that the LHC beam will be produced with single-batch filling of the PS instead of the currently used double-batch operation, thereby freeing some more cycles for ISOLDE during periods with LHC beam requests.

Table 2.2: Expected ISOLDE performance under various upgrade scenarios

	2006		**2007**[1]		**2010**			
Scenario	1.2 s Linac2	**0.9 s** Linac2	1.2 s Linac2	**0.9 s** Linac2	1.2 s Linac2	**0.9 s** Linac2	1.2 s **Linac4**	**0.9 s** **Linac4**
PSB cycles/hour	1300	2250	1210	2110	1270	2200	1290	2240
% of PSB cycles	48	63	45	59	47	61	48	62
Protons/pulse [$\times 10^{13}$]	3.2	3.2	3.2	3.2	3.2	3.2	6.4	6.4
Protons/hour [$\times 10^{16}$]	4.2	7.1	3.9	6.7	4.1	7.0	8.3	14.1
Av. current [μA]	1.9	3.2	1.7	3.0	1.8	3.1	3.7	6.4
Gain factor	0.97	1.64	0.90	1.55	0.94	1.61	1.91	3.28

[1] The figures for 2007 assume only proton operation in the SPS. In the case of ion commissioning (see Section 3.1.1), ISOLDE would benefit from periods when the SPS requires (only) ions.

The final conclusion is that reducing the PSB repetition time from 1.2 to 0.9 s is an important, cost-effective, short-term option that provides a significant gain of ~60% increase in average current (via the number of available cycles) for ISOLDE. In the medium term, another important gain of ~100% increase in average current (via peak current per pulse) can then be achieved with Linac4. Combining the two options will result in an increase of the average current by a factor ~3.3 as compared to the present situation.

2.4 Effect of upgrades on proton beam availability

The effects of some of the proposed accelerator complex upgrades on the proton beam availability for the period 2006 to 2010 are analysed here. The upgrades considered in detail are

i) Reduction of the basic period (and the Linac2 and PS Booster repetition time) from the present 1.2 s to 0.9 s or 0.6 s. Consequently the number of available PSB cycles is increased by either 33% (0.9 s) or 100% (0.6 s). A change of the basic period length also implies modifications of most of the PS and SPS cycles. The effect is, however, rather small on the SPS since the length of the SPS cycles is usually determined by the time required for the cycling and not by the injection flat bottom. More details on the effect of reduced basic period on PS and SPS cycles can be found in Ref. [11]. The beam characteristics (intensity, emittance, etc.) for all users is assumed to be independent of the basic period length.

ii) Increase of the CNGS intensity from 4.4×10^{13} to 7.0×10^{13} protons per SPS cycle. For this option it is assumed that PS and SPS high-intensity performance can be pushed by around 60% as compared to the nominal CNGS scenario. The higher intensity in the PS is achieved by using two consecutive injections from the PSB (double batch filling), similar to LHC operation [12]. Production and characteristics of the beams for all other physics users are to first order identical to the nominal scenario. The main impact of this option is therefore the increased number (factor 2) of PSB cycles required for CNGS operation.

iii) A new Linac4 (160 MeV, H^-) as injector for the PSB [9]. In this scenario it is assumed that the increased injection energy allows doubling the beam brightness in the PSB. Therefore the nominal (and also the ultimate) LHC beam can be produced with a single PSB pulse in contrast to the currently used double-batch scheme, thus reducing the number of required PSB cycles by a factor of two. A similar argument applies to CNGS operation, where the higher intensity (7.0×10^{13}) can be achieved with a single PSB batch for the PS, avoiding the disadvantageous double-batch filling required for option (ii). As discussed above, it is assumed that the PS and SPS can handle the 60% increase in intensity. Finally it is expected that the PSB intensity for ISOLDE can be doubled from the nominal 3.2×10^{13} to 6.4×10^{13} ppp. All other physics beams will be produced as in the nominal scenario.

The comparison of the various upgrades is based on the operation conditions and guidelines that were defined for the performance analysis of Chapter 3 in Ref. [1]. The same supercycle compositions, user priorities and beam requests were assumed. Tables 2.3 to 2.11 summarize the beam availability for all physics users for 2006, 2007 and 2010 for the following three scenarios:

- Present operational beam characteristics (‘standard operation’).
- Increased CNGS intensity of 7.0×10^{13} per SPS cycle (‘CNGS double batch’).
- 160 MeV H^- injection into the PSB (‘Linac4’).

Tables 2.3 to 2.5 are for the present Linac2 and PSB repetition time of 1.2 s, Tables 2.6 to 2.8 assume 0.9 s and Tables 2.9 to 2.11 are for 0.6 s.

ISOLDE performance is quoted in three different ways: pulses per hour, average percentage of PSB cycles, and average current. This is because the present way of quantifying ISOLDE performance by quoting either PSB pulses or percentage of cycles makes little sense when changing the PSB repetition time.

It should be noted that Linac4 is considered a medium-term option that will be available by 2010 at the earliest. Nevertheless, performance figures for this option are quoted for 2006 and 2007 for comparison.

Table 2.3: Beam availability in 2006 with 1.2 s PSB repetition time

	Request	**Standard operation**	**CNGS high intensity**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.4	6.3 (4.5)	7.0 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.3	3.0 (4.5)	3.3 (5.1)
East Area [$\times 10^{6}$ spills/year]	1.3	1.3	1.2	1.3
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.4	1.3	1.4
ISOLDE [pulses/hour]	1350 (50%)	1300 (48%)	930 (34%)	1300 (48%)
Average current [μA]	1.9	1.9	1.3	3.7

Table 2.4: Beam availability in 2007 with 1.2 s PSB repetition time

	Request	Standard operation	CNGS double batch	Linac4
CNGS [$\times 10^{19}$ pot/year]	4.5	4.4	6.3 (4.5)	7.0 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	1.9	1.8 (3.3)	1.9 (3.7)
East Area [$\times 10^{6}$ spills/year]	1.3	1.5	1.4	1.6
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.7	1.5	1.7
ISOLDE [pulses/hour]	1350 (50%)	1210 (45%)	890 (33%)	1260 (47%)
Average current [μA]	1.9	1.7	1.3	1.8
SPS LHC filling cycle [s]	–	21.6	21.6	18.0
SPS LHC pilot cycle [s]	–	22.8	25.2	22.8

Table 2.5: Beam availability in 2010 with 1.2 s PSB repetition time

	Request	Standard operation	CNGS double batch	Linac4
CNGS [$\times 10^{19}$ pot/year]	4.5	4.9 (4.5)	7.0 (4.5)	7.8 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.3 (3.8)	3.0 (5.1)	3.3 (5.7)
East Area [$\times 10^{6}$ spills/year]	1.3	1.5	1.4	1.5
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.7	1.5	1.7
ISOLDE [pulses/hour]	1350 (50%)	1270 (47%)	920 (34%)	1290 (48%)
Average current [μA]	1.9	1.8	1.3	3.7
SPS LHC filling cycle [s]	-	21.6	21.6	18.0
SPS LHC pilot cycle [s]	-	22.8	25.2	22.8

Table 2.6: Beam availability in 2006 with 0.9 s PSB repetition time

	Request	Standard operation	CNGS double batch	Linac4
CNGS [$\times 10^{19}$ pot/year]	4.5	4.2	6.3 (4.5)	6.7 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.2	3.0 (4.5)	3.2 (4.8)
East Area [$\times 10^{6}$ spills/year]	1.3	1.2	1.1	1.2
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.3	1.3	1.3
ISOLDE [pulses/hour]	1350 (50%)	2250 (63%)	1850 (51%)	2250 (63%)
Average current [μA]	1.9	3.2	2.6	6.4

Table 2.7: Beam availability in 2007 with 0.9 s PSB repetition time

	Request	**Standard operation**	**CNGS double batch**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.3	6.3 (4.5)	6.8 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	1.9	1.8 (3.3)	1.9 (3.6)
East Area [$\times 10^{6}$ spills/year]	1.3	1.5	1.4	1.5
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.7	1.6	1.7
ISOLDE [pulses/hour]	1350 (50%)	2110 (59%)	1760 (49%)	2210 (61%)
Average current [μA]	1.9	3.0	2.5	3.2
SPS LHC filling cycle [s]	–	18.9	18.9	18.9
SPS LHC pilot cycle [s]	–	23.4	25.2	23.4

Table 2.8: Beam availability in 2010 with 0.9 s PSB repetition time

	Request	**Standard operation**	**CNGS double batch**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.7 (4.5)	7.0 (4.5)	7.5 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.2 (3.4)	3.0 (5.1)	3.3 (5.6)
East Area [$\times 10^{6}$ spills/year]	1.3	1.5	1.4	1.5
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.6	1.5	1.6
ISOLDE [pulses/hour]	1350 (50%)	2200 (61%)	1810 (50%)	2240 (62%)
Average current [μA]	1.9	3.1	2.6	6.4
SPS LHC filling cycle [s]	–	18.9	18.9	18.9
SPS LHC pilot cycle [s]	–	23.4	25.2	23.4

Table 2.9: Beam availability in 2006 with 0.6 s PSB repetition time

	Request	**Standard operation**	**CNGS double batch**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.4	6.6 (4.5)	6.9 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.3	3.1 (4.7)	3.3 (5.0)
East Area [$\times 10^{6}$ spills/year]	1.3	1.3	1.2	1.3
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.4	1.3	1.4
ISOLDE [pulses/hour]	1350 (50%)	4000 (74%)	3540 (66%)	4000 (74%)
Average current [μA]	1.9	5.7	5.0	11.4

Table 2.10: Beam availability in 2007 with 0.6 s PSB repetition time

	Request	**Standard operation**	**CNGS double batch**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.4	6.6 (4.5)	7.0 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	1.9	1.9 (3.5)	1.9 (3.7)
East Area [$\times 10^{6}$ spills/year]	1.3	1.6	1.5	1.6
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.7	1.6	1.7
ISOLDE [pulses/hour]	1350 (50%)	3880 (72%)	3490 (65%)	3960 (73%)
Average current [μA]	1.9	5.5	5.0	11.3
SPS LHC filling cycle [s]	–	19.8	19.8	18.0
SPS LHC pilot cycle [s]	–	22.8	24.0	22.8

Table 2.11: Beam availability in 2010 with 0.6 s PSB repetition time

	Request	**Standard operation**	**CNGS double batch**	**Linac4**
CNGS [$\times 10^{19}$ pot/year]	4.5	4.9 (4.5)	7.4 (4.5)	7.8 (4.5)
FT [$\times 10^{5}$ spills/year]	7.2	3.3 (3.8)	3.1 (5.4)	3.3 (5.7)
East Area [$\times 10^{6}$ spills/year]	1.3	1.5	1.5	1.5
nTOF [$\times 10^{19}$ pot/year]	1.0–1.5	1.7	1.6	1.7
ISOLDE [pulses/hour]	1350 (50%)	3960 (73%)	3520 (65%)	3990 (74%)
Average current [μA]	1.9	5.6	5.0	11.4
SPS LHC filling cycle [s]	–	19.8	19.8	18.0
SPS LHC pilot cycle [s]	–	22.8	24.0	22.8

2.4.1 Conclusions

The comparison between upgrades highlights that a significant increase of the SPS intensity per pulse for CNGS is a very effective way of improving the performance for CNGS and/or FT, whereas the choice of the basic period length and the PSB repetition time has no important influence on these physics users. A potential way of achieving this is to fill the PS with two consecutive PSB cycles (double-batch operation) and to improve on high-intensity operation of PS and SPS. This has unfortunately the detrimental effect of reducing the number of PSB cycles available to other users. With the present PSB repetition time of 1.2 s, ISOLDE operation would seriously suffer, as can be seen in Table 2.3 to Table 2.5, whereas for the PS (East Area, nTOF, AD) no shortage of cycles or beam availability is anticipated. The straightforward way of improving ISOLDE performance is to decrease the PSB repetition time. For a repetition time of 0.9 s (Table 2.6 to Table 2.8), ISOLDE performance will still be ~30% above request when double batch operation is used for CNGS. A further decrease of the repetition time to 0.6 s is mainly advantageous to ISOLDE which will then reach 2 or even 2.5 times the requested performance.

The installation of Linac4, as injector for the PSB, will significantly increase the proton flux for ISOLDE (~×2), and to a lesser extent, for CNGS and FT (~×1.1). For the LHC, Linac4 is also very valuable for the twice higher brightness that can be achieved in the PSB. Moreover, PSB cycles are freed for other users because LHC nominal and ultimate beams and also very high intensity CNGS-type beams can be produced with single PSB batches. When combined with a shorter basic period of 0.9 or 0.6 s, Linac4 will bring the flux to ISOLDE to 3.4 or even 6 times the nominal request.

2.5 Summary of the recommendations

In the short term, to define in 2004 and start in 2005 the following three projects:

- New multi-turn ejection for the PS.
- Increased intensity in the SPS for CNGS (implications in all machines).
- 0.9 s PSB repetition time.

In the medium term, to work on the design of Linac4, to prepare for a decision on construction at the end of 2006.

In the long term, to prepare for a decision concerning the optimum future accelerator by pursuing the study of a Superconducting Proton Linac and by exploring alternative scenarios for the LHC upgrade.

References

[1] M. Benedikt, K. Cornelis, R. Garoby, E. Métral, F. Ruggiero and M. Vretenar, 'Report Of The High Intensity Protons Working Group', Eds. M. Benedikt and R. Garoby, CERN-AB-2004-022 OP/RF, 2004.

[2] T. Nilsson, ISOLDE Upgrade and Future Plans, HIP meeting, http://ab-div.web.cern.ch/ab-div/Projects/hip/Presentations/HIP-12Feb03-TNilsson.ppt

[3] D. Forkel-Wirth *et al.*, Reflections on Super-ISOLDE, CERN/TIS-RP/TM/2000-18, Geneva, 2000.

[4] Addendum to the Memorandum of Understanding for the Execution of the ISOLDE Experiments at the PS-Booster, CERN, Geneva, 2004.

[5] E. Prebys, FNAL, private communication and M. Popovic, L. Allen, A. Moretti, E. McCrory, C.W. Schmidt and T. Sullivan, High Current Proton Tests of the Fermilab Linac, Linac2000 Conference, Monterey, 2000.

[6] M. Martini and C. Prior, High-intensity and High-density Charge-exchange Injection Studies into the CERN PS Booster at Intermediate Energies, to be published at EPAC 2004, Lucerne, 2004.

[7] M. Martini, Latest Results on 160 MeV H- Injection in the PSB, HIP meeting.

[8] M. Vretenar, Upgrade of the CERN Linacs, HIP meeting, http://ab-div.web.cern.ch/ab-div/Projects/hip/Presentations/HIP-12Mar03-MVretenar.ppt

[9] R. Garoby, K. Hanke, A. Lombardi, C. Rossi, M. Vretenar and F. Gerigk, Design of the Linac4, a new Injector for the CERN Booster, to be published at Linac2004, Lubeck (Germany), 2004.

[10] M. Benedikt and Results of Tests for Linac2 and PSB at 600 ms, PPC meeting, http://psdoc.web.cern.ch/PSdoc/ppc/ppc021122/ppc021122.html

[11] M. Benedikt and G. Métral, Cycling of the PS Complex and the SPS: Analysis and Possibilities for Optimisation, HIP meeting, http://ab-div.web.cern.ch/ab-div/Projects/hip/Presentations/HIP-12Feb03-MB.doc

[12] R. Cappi (editor), K. Cornelis, J.-P. Delahaye, R. Garoby, H. Haseroth, K. Hübner, T. Linnecar, S. Myers, K. Schindl and C. Wyss, Increasing Proton Intensity of PS and SPS, CERN-PS (AE) 2001-041, Geneva, 2001.